HARVARD | BUSINESS | SCHOOL

# Virtual Team Learning: Reflecting and Acting, Alone or With Others

**Deborah L. Soule**
**Lynda M. Applegate**

## Working Paper

**09-084**

Draft: January 2009

# Virtual Team Learning: Reflecting and Acting, Alone or With Others

**Deborah L. Soule**[1]

**Lynda M. Applegate**

**Harvard Business School**

## ABSTRACT

This paper examines virtual team learning in new product development situations. New product development activities manifest novelty, uncertainty and complexity, presenting an extreme need for learning in the course of the work. We present data from an exploratory study of learning processes in globally dispersed new product development teams. These qualitative data are used to investigate components of team learning previously highlighted in the team learning literature—namely reflection-oriented and action-oriented behaviors—and to examine the boundaries of these learning behaviors. We find that effective virtual teams, like co-located teams, engage in both reflective and action-oriented learning behaviors. However, the virtual context highlights distinct participation strategies in teams' learning patterns, which aim to leverage deep, specialist knowledge, on one hand, or seek to integrate diverse knowledge, on the other hand. Moreover, our findings suggest that, in the virtual setting, the boundary of team membership is not centrally associated with different learning behaviors and outcomes, as argued in other team learning research. Instead, virtual team learning behaviors are likely to be shaped by boundaries that delimit timely access to relevant knowledge and skill. In conclusion, we discuss implications for future virtual team learning research.

**Keywords:**
Virtual teams; team learning; reflection; action; boundary conditions.



[1] Contact author: dsoule@hbs.edu.

# INTRODUCTION

Contemporary organizations face a compelling need to learn in the midst of rapidly changing technological, competitive and economic environments (Garvin, 2000; Senge, 1990). The combined influences of rapid technological progress, advancing globalization, and growing corporate competition as a result of industry consolidation and realignment, make learning a differentiating organizational capability more than ever before (Easterby-Smith, Snell, & Gherardi, 1998).

Teams, defined as bounded work groups that exist within a larger organization and which share responsibility for a task (Hackman, 1987), have become prominent in many organizations, developing strategy, designing and producing new products, delivering services and executing other key tasks that affect organizational performance (Edmondson, Dillon, & Roloff, 2007). Engaged as they are in critical organizational activities, such small groups underpin the learning of the larger organizations within which they are embedded (Edmondson, 2002; Senge, 1990). Thus learning is an expanding theme of interest in the study of teams (Bunderson & Sutcliffe, 2003; Edmondson, 2002; Edmondson et al., 2007; Gibson & Vermeulen, 2003).

This study explores learning in virtual teams; more specifically, learning in virtual product development teams. A virtual team is one whose members rely substantially on information and communications technologies (ICTs) to interact across locations and time-zones in pursuit of interdependent tasks and a common purpose (Cramton, 2001; Lipnack & Stamps, 1997; Maznevski & Chudoba, 2000). Virtual teams offer a viable response to expertise constraints created by downsizing, mergers and acquisitions, globalization, and employee mobility preferences (Boutellier, Gassmann, Macho, & Roux, 1998; Townsend, DeMarie, &

Hendrickson, 1998). Moreover, they promise new possibilities for leveraging and integrating relevant and diverse knowledge from across an organization, and thus are increasingly favored for accomplishing complex and nuanced “knowledge work” requiring input from multiple perspectives (Boudreau, Loch, Robey, & Straub, 1998; Townsend et al., 1998).

In particular, virtual product development teams already exist extensively and continue to proliferate as organizations seek to leverage skills and expertise available on a global scale (McDonough, Kahn, & Barczak, 2001). Virtual development teams operate in dynamic technological, intellectual, and/or competitive environments characterized by uncertainty as regards market and customer needs, technical feasibility, and resource availability. Accordingly, these teams’ ability to learn becomes increasingly important to establishing and sustaining effective performance (Edmondson, Bohmer, & Pisano, 2001). Nevertheless, despite a growing body of empirical research on team learning, we know relatively little about how virtual team members approach learning activities, such as recognizing when change is due, evaluating new alternatives, and acting effectively on their choices (Edmondson, 2002), in ways that have a positive impact on their team outcomes. On the contrary, virtual team research highlights many factors likely to hinder team-level learning (e.g. Chudoba, Wynn, Lu, & Watson-Manheim, 2005; Cramton, 2001; Hinds & Bailey, 2003; Jarvenpaa & Leidner, 1999; Sole & Edmondson, 2002a; Straus & Olivera, 2000; Watson-Manheim, Chudoba, & Crowston, 2002).

This study sought to explore *how* virtual teams learn, despite the presence of features of virtual life, such as differences (or “discontinuities” (Watson-Manheim et al., 2002)) in member functions, locations, and organizations, which are expected to complicate learning. Team learning is defined as those activities carried out by team members, through which a team acquires and applies knowledge that enables it to address problems lacking immediately-obvious solutions. Findings reveal virtual development work as an iterative experiential learning process, comprising both reflection and action, in which patterns of participation meet the need for specialized or diverse expertise while simultaneously accommodating the individual or collective participation possible.

## TEAM LEARNING IN THE LITERATURE

*Team learning* research builds on and complements many years of research on *organizational learning* (Edmondson, 2002; Edmondson et al., 2007). This section reviews three aspects of team learning research pertinent to the current study: the conceptualization of team learning itself, conceptualizations of team learning behavior, and conceptualizations of sources of expertise relevant to team learning.

### Team Learning as Outcome or Process

In the organizational learning literature, learning has been discussed as both an outcome (e.g. Levitt & March, 1988) and a process (e.g. Argyris & Schon, 1978). Similarly, team learning has been conceptualized as both an outcome and a process.  Edmondson defines team learning as "the activities carried out by team members through which a team obtains and processes data that allow it to adapt and improve" (Edmondson, 1999,:352). Argote and colleagues (Argote, Gruenfeld, & Naquin, 2000) define group learning as both the processes and outcomes of group interactions through which individuals acquire, share and combine knowledge to address group concerns. This dichotomous understanding of team learning is reiterated in a recent review of empirical team learning research, which identifies three distinct research traditions in team learning: learning curves in operational settings, psychological experiments on team member coordination of task knowledge, and field research on learning processes in teams (Edmondson et al., 2007).

Learning curve research (e.g. Darr, Argote, & Epple, 1995; Edmondson, Winslow, Bohmer, & Pisano, 2003; Pisano, Bohmer, & Edmondson, 2001) generally defines team learning as an improvement in performance outcome (e.g. decreased cost, less waste, reduced time), an approach highly appropriate for studying improvement in the outcomes of team activities to be enacted repeatedly—for example, those of operations teams. However, this conceptual approach to team learning offers relatively less insight into the challenges of innovation and project-based knowledge work, such as those faced by new product development teams, which do not involve repetition of similar tasks (Edmondson et al., 2007).

Team coordination research views team learning as the outcome of effective communication and coordination that builds shared knowledge by team members about their new task, the context, and the available resources, and which is manifest in mastery of a new, interdependent task. A construct central to this stream of research is the transactive memory system (TMS) (Wegner, 1987), which describes team members' knowledge of each other's skills, expertise and task-relevant experience. Studies of the relationship between TMS (and other team-level cognitive constructs) and team outcomes, such as task mastery and group identity, have tested how different interventions—such as collective training, team-building exercises, and discussion of expertise—affect this relationship (e.g. Liang, Moreland, & Argote, 1995; Moreland & Myaskovsky, 2000, Stasser, 1995 #1155). Insights from this tradition explain how, in teams where diverse member expertise is essential, the shared knowledge embedded in a TMS enables teams to interact effectively and efficiently by ensuring that unique individual knowledge is used, allowing specialization, reducing redundant information, and developing informal structures for accountability (Edmondson et al., 2007). These team learning studies can thus inform new product development settings where cross-functional involvement from critical organizational areas, such as research, engineering, manufacturing and marketing, has been consistently linked to development process performance (Brown & Eisenhardt, 1995; Dougherty, 1992). NDP teams often are deliberately composed of *explicitly recognized functional representatives*, and are thus endowed with an initial level of transactive memory predicted to aid team performance (Stasser, Stewart, & Wittenbaum, 1995). Nevertheless, we might also anticipate that *virtual* NPD teams have fewer opportunities to learn of each member's *non-function-related unique expertise and skills*, and thus may suffer in their ability to develop an accurate and complete TMS (Moreland et al., 2000).

Research that emphasizes team learning as a process typically investigates real teams in field settings, with the aim of observing and measuring behaviors that characterize this process (Edmondson et al., 2007). Learning behaviors include seeking feedback and help, gathering information, experimenting, evaluating and responding to feedback, discussing errors and shortcomings, and handling differences of opinion (Brooks, 1994; Edmondson, 1996; Edmondson, 1999). Team learning behavior is associated with features of team climate, particularly psychological safety (Edmondson, 1999) and team leader behaviors (Brooks, 1994; Edmondson, 1996). The present study follows the process perspective, viewing team learning as a series of behaviors through which a team discovers, develops, and applies knowledge to address team tasks and resolve problems that arise during the course of development (Bresman, 2006; Edmondson, 1999; Gibson et al., 2003).

Although research has demonstrated performance benefits for teams engaging in various learning behaviors (Bresman, 2006; Edmondson, 1999), learning behavior does not guarantee positive outcomes thus teams may risk spending more time learning than is effective (Bunderson et al., 2003). For NPD teams, however, which confront many uncertainties related to their product's technology, production, and performance in the marketplace, the performance benefits of learning are expected to outweigh the risks.

**Learning as a cycle of reflection and action**

Conceptualizations of learning as a process have long centered on an iterative cycle of reflection and action (Dewey, 1938; Kolb, 1984; Schon, 1984). Dewey described individual learning as an iterative inquiry process of designing, trying out, and evaluating new actions intended to resolve a problematic situation for which one's habitual responses are found wanting. He noted that a problematic situation is both cognitive and practical, existing in the physical as well as the mental realm. Individual experiential learning theories (Kolb, 1984; Schon, 1984) build on these ideas of learning as a cycle of reflection and action, grounded in firsthand experience.  Extrapolating from the work of Dewey, Kolb and others, to develop models of collective learning, Kim (1993) and Raelin (1997) similarly emphasize the same duality: that effective collective learning entails a conceptual, reflective phase and an active, operational phase. At the group level, Edmondson (1999; 2002) conceptualizes group learning as a ongoing process comprising two basic components—reflection to gain insight and action to accomplish change. Reflection or "thinking" behaviors at the team level includes behaviors such as sharing information, seeking feedback, discussing errors, and analyzing past performance. Action or "doing" behaviors can include making decisions, initiating changes, experimenting, implementing new ideas, making improvements, and transferring new information to other parties. Edmondson's (2002) findings that more effective teams engage in both reflection and action draw attention to how the virtual environment might enhance or inhibit these behaviors. For example, group reflection may be hampered by logistical and technological constraints limiting informal spontaneous interaction (Straus et al., 2000) or by misunderstandings created by limited "mutual knowledge" of each member's technological and local context (Cramton, 2001). Whereas conceptual and reflective activities draw on and develop the mental and intellectual context of team members, action-oriented activities may draw on and reinforce routines operating, by implication, in particular social and physical contexts. Thus group action in virtual teams is expected to be shaped by dispersed members' abilities to participate in particular social and/or physical settings.

**Sources of knowledge for team learning**

Team learning research also has focused attention on different sources of knowledge leveraged in the learning processes (Bresman, 2006; Brooks, 1994; Wong, 2004). Much early team learning research, particularly laboratory-based task mastery research, focused on activities taking place within the team. Building on insights regarding the advantages of "boundary-spanning" activity for team performance (Allen, 1977; Ancona & Caldwell, 1992), recent research turns more attention to learning from across team boundaries. Wong (2004) measured "local learning" (learning from interactions within a group) and "distal learning" (learning by seeking help or information from external parties) in 73 teams. Her results show that local learning predicted team efficiency, while distal learning predicted team innovativeness, negatively moderated team efficiency and suppressed local learning, prompting the recommendation that teams should focus on either local learning *or* distal learning, according to the needs of their task.

Bresman (2006) introduces the concept of vicarious learning—well-established at the level of individual and organizations—into the group learning literature, defining vicarious team learning as the activities by which a team learns key aspects of its task from similar experiences of others outside the team. Bresman's study of pharmaceutical "in-licensing" teams shows that vicarious team learning is distinct from both internal experiential learning (e.g. Edmondson, 1999) and from "contextual learning," that is, more general boundary-spanning behavior through which teams gather general information about how to approach their work (Allen, 1977; Ancona et al., 1992). Further, he demonstrates that vicarious learning offers distinct performance benefits.

The internal-external (or local-distal) classification of knowledge sources for team learning implies that team membership is the key boundary factor shaping how and what teams learn. Virtual NPD teams, however, exhibit multiple internal boundaries marking differences in functions, locations, or organizational affiliations, for example, which influence how and with what effect those teams exchange and process knowledge (Cummings, 2004; Sole & Edmondson, 2002b). Thus we expect that other boundaries may emerge as prominent in influencing virtual team learning.

## METHODS

To explore these themes, we gathered longitudinal, qualitative data on the learning and working practices of seven new product development (NPD) teams in a multinational company referred to as FILMCO, which designed and produced polymer film products for industrial and consumer applications. At the time of data collection, FILMCO routinely staffed virtual new product development teams from different research centers, production sites, and commercial offices around the world. Multidisciplinary development input was essential to manage the inherent interactions among the chemical structure and molecular behavior of the initial raw materials, the particular processing mechanisms used, and the desired end-use characteristics of each product.

Film design offered scope for both conceptual and operational variation. Owing to recent acquisitions, FILMCO's portfolio included two product lines whose products overlapped in terms of properties and potential applications but which were based on very different film manufacturing techniques. Even from site to site within the original companies, production assets and techniques varied substantially, resulting in idiosyncratic production knowledge at each site. Interviews indicated that successful processing techniques had been identified largely as a result of trial and error over many years. Moreover, references to "the almost craft-like nature of the film-making process" and "black magic" hinted that, despite general knowledge of material-process interactions, the underlying chemical and molecular mechanisms of film behavior and its relationship to processing techniques remained partially tacit.

**Data Collection**

We collected data primarily via 70 semi-structured interviews (recorded and transcribed) conducted with team members, their management and other development participants. Recognizing the potential for retrospective response biases in interviewees' reports (Huber & Power, 1985), we sought to minimize, by a number of means, the potential for construct invalidity. In addition to assurances of anonymity, these included triangulation of data from different sources (e.g. team members and management) and through different techniques. Real-time access to electronic project records over twelve months, plus observations of team work practices at two FILMCO sites during four periods in the field, provided multiple perspectives on issues and permitted cross-checking of existing and emerging concepts (Eisenhardt, 1989; Glaser & Strauss, 1967).

Through our FILMCO contact, we identified seven teams that met the criteria of interest to the investigation: they exhibited both cross-functional representation and geographic dispersion; development activity was in-progress; they had access to a variety of collaborative technologies; and members were available for interviews and observations during four periods in the field. The teams varied in team size, project complexity and the extent of their geographical distribution. Team members were supported in both mediated and unmediated interactions by a variety of communications and collaborative technologies providing support for "same time, different place" interactions (e.g. audio-conferencing, video-conferencing, and application sharing tools) and for "different time, different place" interactions (e.g. email, online discussions, workflow organization tools, and electronic document repositories). Team characteristics are summarized in Table 1.

[Insert Table 1 about here]

FILMCO product development projects generally followed a "stage-gate" methodology (Cooper, 1990) that identified key phases, milestones, and deliverables on the path towards the final product.  Each team was studied retrospectively and in real-time over a series of months. Real time study occurred primarily during each project's Design and/or Prototype stages when teams experienced the most need to integrate diverse knowledge about the market opportunity, potential materials, likely equipment, and possible processing techniques.[2]

Interviews with a cross-section of the development community at both field sites (e.g. managers, research chemists, engineers, technicians, operators, customer and technical support representatives) yielded data on both general development activities and specific projects, types of knowledge and learning invoked during development, the use of collaborative technologies, and norms of learning behavior at each site. Interviews with team management focused on the teams' performance and project progress.

Interviews with team members sought to derive a general account of each project's progress, including key milestone events, as experienced by each informant; thus providing a means for comparison of accounts and for generating a baseline account of the project. An adaptation of Flanagan's (1954) critical incident technique (CIT) focused respondents' attention on those particular incidents or episodes during the project, which they considered significant learning events, yielding details on the genesis, evolution, and resolution of "significant learning episodes" for each team. This technique offered insights into specific learning behaviors in complex settings involving a high degree of uniqueness and judgment in work approaches (Flanagan, 1954; Schon, 1984).

[2] FILMCO developments followed five stages:

- Concept: exploring the physical and economic feasibility of an idea;
- Design: translating critical customer requirements into quantitative base film properties, iterating through experiments and pilots-scale trials;
- Prototype: producing product on full-scale manufacturing equipment for customer feedback;
- Scale-up and Qualification: assuring robustness and reproducibility of the manufacturing process for large volumes, verifying product performance in down-stream conversion processes and ultimate application;
- Controlled Commercial: monitoring commercial launch for 4-6 months by original development team, before transferring responsibility to manufacturing organization.

Once teams were chosen for detailed study, we examined the historical document archives associated with each project, with a view to correlating the documents' form, timing, and content with interviewee accounts. Project documents included team meeting minutes, project reports and presentations, and feedback from project tasks such as customer visits, analytical evaluations, and manufacturing trials.  Prepared by project participants in real-time, these materials provided an effective means to cross-check informants' retrospective reports and observed behaviors. Subsequently, we checked the repository periodically—once a week, on average—to follow the ongoing project documentation for the seven teams under study.

During periods on site, the virtual and physical activities of teams—particularly the first two teams—were "observed," offering further insight into how team members learned about the needs of their project and approached particular tasks. Events included on-site meetings, teleconferences, casual encounters and conversations, visits to pilot and production facilities, and practical activities such as running experiments. Occasions to observe manufacturing activities on a range of production facilities at one site and to attend an overnight pilot trial by one of the teams at another site provided insight into physical aspects of the development process. Attendance at site meetings and events, informal interactions, discussions, and excursions with organizational members provided additional insight into FILMCO development work.

**Data Analysis**

Coding and analysis of the qualitative data advanced iteratively (Eisenhardt, 1989; Glaser et al., 1967), with earlier stages focusing on themes suggested by existing literature, and latter stages being guided by new concepts identified in preliminary analyses. Our initial analysis noted themes related to sources of knowledge (e.g. reference to the skills, expertise, or experience of oneself or other individuals) and themes related to learning behaviors (e.g. seeking information, providing expert assistance, discussing options, reflecting on project progress and intermediate outcomes, salvaging insight from apparent failures, and instigating experimental actions) previously identified in the literature.

*Within-team analysis* compared informants' accounts to develop a baseline account for each project, which documented team composition and distribution, history and status of the project, project complexity, origins of key product and process knowledge for the project, team technology use and patterns of interaction, and overall performance. Using collective input from multiple informants, corroborated by online records, a multi-dimensional narrative for each learning episode was developed. The term 'episode' rather than 'incident' conveys informants' revelations of a series of related activities and decisions unfolding over time to culminate in a particular insight. Some episodes were associated with successfully passing project milestones and had a strong task orientation. Other episodes were salient because of initial unexpected difficulties that were, surprisingly, not technical difficulties but the result of organizational or procedural misunderstandings.

The primary source for *analysis across teams* was the set of learning episodes. Selected by participants in the light of their ongoing learning and experience, the 51 learning episodes offer a degree of authenticity—both in terms of their individual complexity and their collective variety—which provided valuable insight into the learning patterns and constraints of teams in virtual environments. Despite the inherent variety evident in these learning episodes, they presented a common structure: the presence of a problem or "knowledge gap" perceived by some or all team members; a "learning response," the learning behavior triggered by the gap; and, ultimately, a concluding action or decision deemed a learning outcome. Analysis focused on identifying common and contrasting features of the learning behaviors identified earlier, and on conditions explaining these variations. This level of attention yielded prominent dimensions of learning responses from which four learning practices emerged.

## PATTERNS OF VIRTUAL DEVELOPMENT TEAM LEARNING

We present our findings in two parts. First, we present a general description of development work, revealing an overall pattern of experiential learning within, by and beyond the virtual team. Next, we offer a data-derived typology of virtual team learning practices.

### Development Work as Team-based Experiential Learning

Experiential learning involving iterations of reflection and action has been identified in individuals (Kolb, 1984; Schon, 1984) and in teams (Edmondson, 1999; Edmondson, 2002). This pattern was found to prevail in the work of virtual development teams as well.

Development teams must perforce learn *as they work* to produce innovative products or implement innovative processes. The novelty and complexity of their work continually presents problems, or "knowledge gaps," to which they must respond by creating or discovering—rather than simply applying—solutions. Despite the apparent linearity of the development methodology, in reality, each stage consisted of a series of iterative activities during which a team experimented with potential solutions that approximated ever more precisely the targeted deliverables for each stage. For example, in the "Design" stage, teams sought to identify product designs that would yield physical properties satisfying the end-use characteristics specified by the customer or application. In this discovery process, teams engaged in successive cycles of learning involving: abstract conceptualization of a design; active experimentation to manufacture the product as designed; concrete experience of that endeavor and its physical result; reflection on the result; and again (re)conceptualization of the design that was newly informed by the team's experiences and reflections thereon (see Figure 1.)

[Insert Figure 1 about here]

Design conceptualization. In conceiving an initial design, development teams operated primarily in the theoretical realm, selecting a product's composition and structure based on their discipline-based (e.g. physical, chemical, engineering) theoretical knowledge of generic relationships between material properties and environmental conditions. For example, the BIANCO team sought to make a low-cost, high-functionality product for a strategic customer. They used, as a starting point for the design, the composition of an existing film product, whose aesthetic properties had been approved by the customer, but focused on designing a different film structure so as to achieve the lower cost requirements.

Teams also drew heavily from prior knowledge of specific relationships, which was either encoded in the composition and structure of existing products or embedded in existing production techniques. GROSSO, a high-end product required to withstand severe operating conditions, was conceived from the combined application of patented product composition expertise and patented processing techniques, and thus was solidly grounded in well-established and formally encoded organizational knowledge. A manager involved in GRIGIO described how that project too was initially conceived in terms of past organizational experience encoded in prior products—dyed films—and embedded in existing manufacturing processes—incorporating dye and UV stabilizers.

> We'd had experience with dyed films before. We've made blue films for x-ray and we've put dye into film and it's not all that difficult. So I think what we thought was, "Jeez, how difficult is it

> going to be to pour some dye into the [GRIGIO] film and have it look right? It's not a big deal. We add UV stabilizers to film already. We add dye to film already…"

Conceptualization involved analyzing and interpreting information about component materials—such as their chemical and physical behavior, or their economic and environmental costs—rather than working directly with the physical materials themselves. Despite their geographical separation, all suitably-skilled team members usually were able to participate in these thought exercises. This broad participation was important since inherent interactions between the product design and both the means and cost to produce that design demanded concurrent input from scientific, engineering, commercial, and production perspectives. For example, in deciding on an initial product design BIANCO team members engaged in repeated teleconferencing sessions where they debated the relative merits and disadvantages of possible product structures. In these sessions, they were able to simultaneously incorporate different members' insights about 1) the product capabilities sought by the customer, 2) the production capacities and scope of potential manufacturing lines, and 3) the likely behavior of component materials. This synthesis of expertise and insight was achieved in spite of having members spread twelve time-zones apart.

<u>Active experimentation.</u> Once an initial design was chosen, a team's learning shifted into the practical realm as it undertook small-scale "trials" to determine whether it could feasibly manufacture the product as designed. In implementing a trial, a team's theoretical understanding of the chosen product formulation, the mixture of material ingredients, was confronted by the physical reality of those materials interacting with processing equipment in a particular setting. Trial operators learned as they transformed the theoretical specifications into tangible physical effects and experienced the confirmation or otherwise of their expectations. For example, a

design might call for certain proportions of ingredient materials in a mixture, or recommend certain equipment settings. Operators carrying out these instructions would learn from how smoothly and predictably the trial unfolded as to whether the theoretical knowledge accurately matched practical reality. Often there were gaps between the theory and practice as the production technician in BIANCO explained,

> There're a lot of things that look good on paper that won't work in the real world too well. …I see that a lot of time from the product development of coatings…. [the scientists] will bring a coating over here [saying] "this works." [In the laboratory], they just spread it on the film and stick it in the oven and it works good. Now if you bring it down to a production line and try to put it on film moving continuously for many hours, it's a whole different world down there. The coating doesn't look well on the film, or it's just a mess to try to clean up on the equipment and all. So yeah, we see it. … there're some ideas … they looked real good from the concept but they didn't work out the way we wanted them to.

Individuals' ratings of an experience as, for example, "good" or "just a mess" were based on their prior experiences in similar experimental situations and their understanding of the aims of the current development.  Team leaders played a key part in building broad-based team understanding of the wider project goals. As the GROSSO team leader noted, specialty or high-performance products were generally more complex to process than the industrial products operators were more used to manufacturing; however, the higher margins they offered made the effort worthwhile:

> Your average operator wants to make film that is easy to process…. [My other specialty product] was splitting all the time; it's difficult to work with so the operators hate it. … And GROSSO is another example of this. They'll say, "Oh, this can't be done." But it can be done; we just have to change the way that we work. We have to change these attitudes on certain production units. And there are certain key people that we need to have 'chime in' at difficult moments to say, "this is worthwhile, we should be going for more specialty products, we should be doing this, even if these projects are difficult."

Each time a trial was undertaken, team members' tacit expectations of what should happen would shift, as they gradually accommodated their prior experiences to the requirements of the new product and process.

Because experimentation was a physical exercise, it was, by definition, located in a physical place such as in a specific laboratory or at a particular manufacturing site. Unless the dispersed team intentionally congregated at that location, it was rare that all members would experience first-hand the sights, sounds, and smells of that exercise. Thus the learning behaviors of particular team members—and the corresponding new insights they gained—could diverge from those of the whole team at such times.

Concrete experience. In addition to learning through active participation in a trial, the physical product resulting from the trial also provided tangible evidence and consolidation of that activity. This tangible evidence was central to the way new knowledge of a development initiative was recorded and conveyed. A CHIARO engineer stressed how product samples served as "proof" of the team's knowledge:

> It is important that our confidence was expressed based on what we'd seen, to give other people confidence that we had a process worth supporting. Experimental data makes it communicable to others; without experimental data, people are more skeptical. With film in their hands, we can say we've done it. People originally doubted we could get a layer thin enough [for the CHIARO application]. The 2nd experiment proved it was possible; [that we] could get down to and below that level [of thinness]. That sparked the confidence that we had [found] a method that could do the job.

Although a product could be "specified" in terms of a minimum set of physical or chemical properties, it also encompassed characteristics difficult to describe precisely in words or numbers. Thus the concrete experience of seeing and touching the product was important for gaining knowledge of a product's suitability for particular purposes or contexts. BIANCO's product development engineer highlighted the role of visual inspection, in describing unexpected trial results:

> So we started making that product and, lo and behold, we started seeing something on the film that was unusual. At first glance, the film looked good, then I flipped the film and on the back side there was a visual fault there – it just looked different, it was unusual. …We didn't know if it was a problem or not.

This description conveys the tacitness of his knowledge about what the product should have looked like, as well as his difficulties in articulating what was different and in evaluating this difference. He explained that they sent samples with this “fault” to the customer for feedback “to find out [from them] if it was a problem.” Such reliance on a customer’s concrete experience to evaluate the product highlights the physical, practice-based dimension of learning. Although not as instantly portable as information about the product (e.g. the product specification), samples could be physically distributed to key stakeholders in the development process for direct examination. Each of BIANCO, GRIGIO, SCURO and NERO conveyed their current knowledge to their customers through sharing samples, and were, correspondingly, able to learn from their customers’ responses to and feedback about those physical samples.

Reflection. Following design trials, teams consciously assessed their trials and the results, in this way transforming their apprehension of a physical reality into intellectual comprehension (cf. Kolb 1984). Most trial experiences were documented by key team members in “trial reports,” which recorded not only the factual elements of the trial but also described and interpreted the first-hand, subjective experience of the process for other—often remote—members of the team and for a broader audience.

New knowledge was often experienced initially at the level of sensation rather than reason—for example, the product “looked good” or the process was “just a mess.” If knowledge remained in this somewhat tacit state, subsequently communicating insight from that individual experience to the overall team could be difficult. When multiple team members participated in a physical experience, they had opportunity to reflect collectively, making more explicit sense out of their experiences. CHIARO’s market development engineer explained how, through continuous discussions about what he and two other team members were seeing during their first experimental trial, they gained a richer understanding of the underlying chemical processes:

> The three of us decided to … try it out, with [Process design engineer] providing engineering expertise, [Experimental scientist] the chemistry aspect, and myself providing chemical expertise and management "aircover". We worked with [a supplier]…we ran some trials on their kit (equipment) to try and prove the design principle. While we were running the trials there was a lot of time to talk so we had these multidisciplinary discussions and ended up with a more robust understanding of what was going on.

These discussions led them to refine the product design (the product recipe) but also to revisit the engineering specifications of the equipment that they had planned to use.

In summary, we found that virtual development entailed cycles of team-based experiential learning, in which virtual teams drew on the experiences and past expertise of both individuals and collectives to meet their task goals. In doing so, they actively sought and integrated the expertise and insight of others beyond the team—customers, suppliers, and internal FILMCO specialists—into the process. Thus new team knowledge was built both on internal experimentation and experiences, as well as on expertise gained from others externally (Bresman, 2006).

**A Typology of Virtual Team Learning Practices**

The preceding description shows the virtual development teams in this study engaged in experiential learning—specifically, behaviors of reflection, conceptualization, experimentation and observation—in response to perceived "knowledge gaps."

Since virtual teams did not share a "place" of learning, a salient dimension of learning behavior, as indicated by the "knowledge gap," was the extent to which it was tied to a particular context or physical environment. This dimension of a team's learning response, labeled the *mode of learning*, distinguished between "thinking" learning behaviors and "doing" learning behaviors (cf. Edmondson's reflection and action, 2002). The former category fore-grounded "thinking" activities of conceptualization and reflection; these activities advanced the team's understanding of problems with minimal concern for place. It included behaviors such as sharing and exchanging information, seeking feedback, discussing errors, failures and unexpected results, and analyzing product, process, or overall project performance. The latter category involved context-specific "doing" actions, experiments, and observations that generated new knowledge towards a problem solution. These included behaviors such as conducting product and equipment tests, undertaking production trials, observing supplier and client processes, and investigating new sources of materials or information.

Development teams also were intentionally composed of members with diverse occupational skills and expertise relevant to the project, suggesting that each team member might be differentially engaged in learning occasions, according to his or her areas of expertise (Stasser et al., 1995). Specifically, members considered "expert" would naturally assume responsibility for team problems clearly in their domain of expertise. This indeed was the case in all seven virtual teams studied as, for example, CHIARO's process design engineer confirmed:

> Roles? Very clear – the engineering side definitely comes to me, the polymer side to [the chemist]. No overlap there. [The project founder] was definitely the commercial side. Within the small team we covered the three essential elements – looking after cash, polymer, and engineering.

Similarly, the experimental scientist from GROSSO explained that:

> We're trying to use experts in their own field. For example, we're trying to tailor the [production] process, so [the process engineer] (acknowledged as a resident processing expert) is involved in those experiments. … But I'm largely the expert for testing samples – I would run things like that on my own.

Analysis of the learning episodes revealed that teams regularly sought to match the problem to individual domain expertise recognized within or proximate to the team, triggering a participation strategy relying on deep expertise of a single specialist. However, when a knowledge gap was ill-defined or unclearly bounded, such that it did not immediately resolve into sub-problems matching the expertise currently available (and recognized) in the team, teams readily sought to involve participants with different experience and perspectives who could offer complementary insights into the problem (Brown et al., 1995). As one technical member put it, describing CHIARO's early challenges:

> There're a lot of "might-bes" or "possibles." And it'll be like that for a little while, because there're many, many variables in this. We've got so many outside variables to think of so at this stage we're just collating our ideas. We're trying to accommodate a commonsense view for the way forward.

In this regard, these virtual teams behaved similarly to co-located teams comprised of specialized individuals: exhibiting role differentiation and specialization when appropriate, in order to leverage expertise efficiently (cf. Levesque, Wilson, & Wholey, 2001).

In the virtual setting, however, division of labor also often was a necessity rather than a choice. For example, information-creating tasks such as running analytical and physical tests on new products were limited to those present at a location where the relevant test equipment was available. Similarly, pilot production trials for each of the GRIGIO, NERO and BIANCO projects were undertaken only by those teams' members located at the one site possessing appropriate, small-scale (prototype) manufacturing facilities. Therefore, a team member's participation in learning was determined not only by having relevant skills and expertise but also by his/her access to the context (e.g. relevant equipment and facilities) in which appropriate learning could take place. The contextual constraints on learning in virtual teams thus emphasized who chose or was chosen to be involved, a dimension of virtual team learning labeled a *participation strategy*. Two primary participation strategies were highlighted in the learning responses of the teams studied: a strategy of leveraging individual specialist knowledge and a strategy of integrating diverse knowledge and multiple perspectives. The former strategy, dependent on a single individual, was unencumbered by the spatial and temporal configuration of the rest of the team. The latter strategy, however, was increasingly constrained by *where* people were located and *when* they were available.

[Insert Table 2 about here]

[Insert Figure 2 about here]

A virtual team's possible learning response to a knowledge gap thus involved the simultaneous choice of a participation strategy and a mode of learning, resulting in four distinct learning practices, *thinking alone, thinking with others*, *doing alone* or *doing with others* (see Figure 2.). Cross-team analysis of the 51 learning episodes showed that all seven teams exhibited these learning practices. Evidence supporting these types is shown in Table 2.

## DISCUSSION

This study sought to explore nuances of team learning that might be unique to virtual teams. The choice of new product development as a research context was deliberate in that it presented both a high need for learning and a team configuration, entailing both occupational diversity and geographic dispersion, in which learning was likely to be more problematic (Cramton, 2001; Dougherty, 1992). In this real-world setting, where internal innovation goals, customer relationships, and deadlines were at stake, these seven teams were largely successful in accomplishing their challenging development goals. Thus our findings, based on 51 significant learning episodes derived from team data, are especially revealing of what it takes to succeed in dispersed development work.

In the dispersed setting, two dimensions of learning behavior, namely the *mode of learning* ("thinking" or "doing") and the *participation strategy* (independent or collective participation), were salient because they varied in their dependence on the physical context and on the team's spatial and temporal configuration. In combination, these two dimensions defined a basic repertoire of four virtual team learning practices: *thinking alone, doing alone, thinking with others,* and *doing with others.* Each of these learning practices was exhibited by all of the teams studied. Teams did vary, however, in when and how much they enacted one or another practice, suggesting variation in conditions influencing virtual teams' choices of learning behavior.

Although team members were selected for development projects primarily on the basis of their disciplinary or occupational expertise, the data suggested that occupation-based knowledge was only one aspect of knowledge shaping a virtual team's choice of who to involve in learning and how. Development participants were also sought out for knowledge of local resources, conditions and work practices, awareness of local "experts," or an understanding of local priorities, assumptions and values (cf . Sole et al., 2002b). Different occupation-based perspectives among participants have been shown valuable for addressing complex problems but also have the potential to cause confusion and misunderstandings (Bechky, 2003; Dougherty, 1992). Similarly, geographic dispersion has been shown to confer unique awareness and access to location-based knowledge (Sole et al., 2002b) but presents logistical and interpersonal hurdles for collaboration and knowledge sharing (Cramton, 2001). We thus propose that virtual team members' combined occupation-based and location-based knowledge will influence their choices of learning practices and the effectiveness of that learning.

In these virtual teams, the ability to learn by "thinking alone" was unconstrained by the spatial and temporal distribution of other members. Learning by "doing alone" required access to the relevant setting but was otherwise similarly independent of other team members. Spatial dispersion limited members' inherent ability to participate in active experimentation and hands-on experience unless they were local to, or could travel to, the problem setting. Spatial dispersion was, however, less restrictive when team members needed to "think with others" since this learning behavior could be independent of a particular setting. Nevertheless, remote interactions still challenged members to effectively express their own knowledge and to adequately comprehend each other's knowledge. As team members became more widely dispersed, such that temporal distances became critical, it became more difficult for them to "think" and "do" effectively with each other. Temporal dispersion across multiple time-zones limited members' inherent ability to interact and receive feedback in a timely manner, and thus affected the ease with which they were able to conceptualize and reflect together. We thus propose that a virtual team's spatial and temporal configuration is likely to influence the team's propensity to engage in different virtual team learning practices.

Collaborative technologies have potential to moderate the effects of a virtual team's physical and temporal dispersion on its collective "thinking" and "doing" learning behavior. The seven teams studied here had access to a variety of collaborative tools but differed in their use of these tools, in ways that often seemed unrelated to the problem at hand. We suggest there is value in future research that explores, in more detail, the role of different collaborative technologies in supporting the virtual team learning practices identified in this research. We also suggest that our typology of virtual team learning practices can be useful in exploring the likely benefits of particular technologies to different kinds of virtual teams. The typology also can inform the design of future collaborative tools.

Our data also suggested that successful virtual development teams—those teams that effectively learn how to respond to the stream of problems and knowledge gaps continually arising in their novel work—draw on their full repertoire, demonstrating flexibility in both how and when they apply their own and others' knowledge resources to address those problems. They exhibit both reflective and active learning, adapting as necessary to the physical limitations placed on various members at different times. They are ready to rely on individual expertise—both within and beyond the team—to learn when efficiency is at a premium; for example when speed or cost is the main concern. They also are able to exert themselves to integrate their diverse perspectives when effectiveness is critical—for example, when making the right decision is more important than making it fast. They do this regularly, in spite of the simultaneous challenges created by the presence of a tough problem, the involvement of multiple domains of expertise, and the constraints on spontaneous interaction imposed by distance and technology filtering effects (Straus & Olivera, 2000). They also demonstrate an ability to switch from reliance on specialist knowledge to diverse knowledge, and visa versa, as the nature and complexity of the problem changes over time. We thus propose that the capacity to engage effectively in a repertoire of different learning practices is crucial for teams comprising members from diverse functions and locations.

Although this study did not distinguish *a priori* between internal (or ”local”) and external (or ”distal”) learning sources, a distinction central to some team learning research (Ancona et al., 1992; Bresman, 2006; Brooks, 1994; Wong, 2004), we did find, as in prior product development research, evidence that virtual teams learn from both kinds of sources. Indeed, because spatial and temporal distances could limit, delay or prohibit learning interactions among sets of team members, these teams often turned to local but non-team colleagues as “a sounding board” in reflection-oriented learning or as “a helping hand” in action-oriented learning. The fluidity and frequency of this type of substitute participation suggested that membership in the virtual team is not the critical boundary condition influencing learning, as suggested in other team learning research. Instead, virtual team learning practices appear to be more strongly shaped by boundaries that delimit timely access to relevant resources.

**Limitations**

The main limitations of this study can be discussed as simplifications and omissions. In this study, the terms “virtual” and “geographically dispersed” were used synonymously, emphasizing spatial and temporal differences among members. Dispersion, here, also assumed a binary value; teams were either dispersed or not. Recent virtual team research argues, however, that our understanding of team dispersion can and should be further finessed (O'Leary & Cummings, 2007). In this research, variations in teams’ spatial and temporal configurations, such as the presence of isolates or clusters (O'Leary & Mortensen, 2005), or the extent of overlapping work hours (O'Leary & Cummings, 2007) were also not characterized explicitly. Consideration of these subtle varieties of virtuality suggests refinements for future virtual development team research.

This study did not explicitly address the role of psychological safety, a prominent construct in team learning research (Edmondson et al., 2007), in team virtual interactions. The related topic of trust in virtual team interactions was a prominent thread in the data, however, although it has not been discussed here.

**Contributions**

This study contributes conceptually and empirically to the study of team learning by refining our understanding of team learning behaviors in virtual settings and categorizing real virtual team learning practices. It identifies conditions likely to shape choices among these practices at the team level, and suggests avenues for future research. In addition, our choice of new product development as team task addresses Edmondson et al's call for research that investigates specific kinds of teams facing specific challenges with real world importance (Edmondson et al., 2007).

**REFERENCES**

Allen, T. J. 1977. ***Managing the Flow of Technology: Technology Transfer and the Dissemination of Technological Information Within the R&D Organization***. Cambridge, MA: MIT Press.

Ancona, D. G., & Caldwell, D. F. 1992. Bridging the Boundary: External Activity and Performance in Teams. ***Administrative Science Quarterly***, 37(4): 634.

Argote, L., Gruenfeld, D., & Naquin, C. 2000. Group Learning in Organizations. In M. E. Turner (Ed.), ***Groups at Work: Advances in Theory and Research***. New York: NY: Erlbaum.

Argyris, C., & Schon, D. A. 1978. ***Organizational Learning***. Reading, MA: Addison-Wesley.

Bechky, B. A. 2003. Sharing meaning across occupational communities: The transformation of knowledge on a production floor. ***Organization Science***, 14: 312-330.

Boudreau, M.-C., Loch, K. D., Robey, D., & Straub, D. 1998. Going Global: Using information technology to advance the competitiveness of the virtual transnational organization. ***Academy of Management Executive***, 12(4): 120-128.

Boutellier, R., Gassmann, O., Macho, H., & Roux, M. 1998. Management of dispersed product development teams: The role of information technologies. ***R&D Management***, 28(1): 13-26.

Bresman, H. 2006. Lessons learned and lessons lost: A multi-method field study of vicarious team learning behavior and performance, ***Academy of Management***. Atlanta.

Brooks, A. K. 1994. Power and the production of knowledge: Collective team learning in work organizations. ***Human Resource Development Quarterly***, 5(3): 213-235.

Brown, S., & Eisenhardt, K. 1995. Product Development: Past Research, Present Findings, and Future Directions. ***Academy of Management Review***, 20(2): 343-378.

Bunderson, J. S., & Sutcliffe, K. M. 2003. Management Team Learning Orientation and Business Unit Performance. ***Journal of Applied Psychology***, 88(3): 552.

Chudoba, K. M., Wynn, E., Lu, M., & Watson-Manheim, M. B. 2005. How virtual are we? Measuring virtuality and understanding its impact in a global organization. ***Information Systems Journal***, 15(4): 279.

Cooper, R. G. 1990. ***Winning at New Products***: Addison-Wesley.

Cramton, C. D. 2001. The Mutual Knowledge Problem and its Consequences for Dispersed Collaboration. ***Organization Science***, 12(3): 346-371.

Cummings, J. 2004. Work Groups, Structural Diversity and Knowledge Sharing in a Global Organization. ***Management Science***, 50(3): 352-364.

Darr, E. D., Argote, L., & Epple, D. 1995. The Acquisition, Transfer and Depreciation of Knowledge in Service Organizations: Productivity in Franchises. ***Management Science***, 41(11): 1750-1762.

Dewey, J. 1938. ***Logic: The Theory of Inquiry***. New York: NY: Holt.

Dougherty, D. 1992. Interpretive Barriers to Successful Product Innovation in Large Firms. ***Organization Science***, 3(2): 179-202.

Easterby-Smith, M., Snell, R., & Gherardi, S. 1998. Organizational Learning: Diverging Communities of Practice. ***Management Learning***, 29(3): 259-272.

Edmondson, A. C. 1996. Learning From Mistakes Is Easier Said Than Done: Group and Organizational Influences on the Detection and Correction of Human Error. ***Journal of Applied Behavioral Science***, 32(1): 5-28.

Edmondson, A. C. 1999. Psychological Safety and Learning Behavior in Work Teams. ***Administrative Science Quarterly***, 44(2): 350-383.

Edmondson, A. C. 2002. The Local and Variegated Nature of Learning in Organizations: A Group-Level perspective. ***Organization Science***, 13(2): 128-146.

Edmondson, A. C., Bohmer, R. M., & Pisano, G. P. 2001. Disrupted Routines: Team Learning and New Technology Adaptation. ***Administrative Science Quarterly***, 46: 685-716.

Edmondson, A. C., Dillon, J. R., & Roloff, K. S. 2007. Three Perspectives on Team Learning: Outcome improvemen, task mastery, and group process. In A. Brief, & J. Walsh (Eds.), ***The Academy of Management Annals***, Vol. 1.

Edmondson, A. C., Winslow, A. B., Bohmer, R. M. J., & Pisano, G. P. 2003. Learning How and Learning What": Effects of Tacit and Codified Knowledge on Performance Improvement Following Technology Adoption. ***Decision Sciences***, 34(2): 197.

Eisenhardt, K. 1989. Building theories from case study research. ***Academy of Management Review***, 14(4): 532-550.

Flanagan, J. C. 1954. Critical Incident Technique. ***Psychological Bulletin***, 51(4): 327-358.

Garvin, D. 2000. ***Learning in Action: A Guide to Putting the Learning Organization to Work***. Boston, MA: Harvard Business School Press.

Gibson, C., & Vermeulen, F. 2003. A healthy divide: Subgroups as a stimulus for team learning behavior. ***Administrative Science Quarterly***, 48: 202-239.

Glaser, B., & Strauss, A. 1967. ***The Discovery of Grounded Theory: Strategies of Qualitative Research***. London: Wiedenfield and Nicholson.

Hackman, J. R. 1987. The design of work teams. In J. Lorsch (Ed.), ***Handbook of Organizational Behavior***. Englewood Cliffs, NJ: Prentice-Hall.

Hinds, P., J. , & Bailey, D., E. 2003. Out of Sight, Out of Sync: Understanding Conflict in Distributed Teams. ***Organization Science***, 14(6): 615.

Huber, G. P., & Power, D. J. 1985. Retrospective Reports of Strategic-Level Managers: Guidelines for Increasing Their Accuracy. ***Strategic Management Journal***, 6(2): 171-181.

Jarvenpaa, S., & Leidner, D. 1999. Communication and Trust in Global Virtual Teams. ***Organization Science***, 10(6): 791-815.

Kim, D. H. 1993. The Link between Individual and Organizational Learning. ***Sloan Management Review***(Fall): 37-50.

Kolb, D. 1984. ***Experiential Learning: Experience as the Source of Learning and Development***. Englewood Cliffs, NJ: Prentice Hall.

Levesque, L. L., Wilson, J. M., & Wholey, D. R. 2001. Cognitive divergence and share mental models in software development project teams. ***Journal of Organizational Behavior***, 22: 135-144.

Levitt, B., & March, J. G. 1988. Organizational Learning. ***Stanford University Annual Review of Sociology***, 14: 319-340.

Liang, D. W., Moreland, R., & Argote, L. 1995. Group versus individual training and group performance: The mediating role of transactive memory. ***Personality and Social Psychology Bulletin***, 21(4): 384-.

Lipnack, J., & Stamps, J. 1997. ***Virtual Teams: Reaching across space, time and organizations with technology***. New York: John Wiley and Sons.

Maznevski, M. L., & Chudoba, K. M. 2000. Bridging Space over Time: Global Virtual Team Dynamics and Effectiveness. ***Organization Science***, 11(5): 473-492.

McDonough, E. F., Kahn, K. B., & Barczak, G. 2001. An investigation of the use of global, virtual and collocated new product development teams. ***Journal of Product Innovation Management***, 18(2): 110-120.

Moreland, R. L., & Myaskovsky, L. 2000. Exploring the performance benefits of group training: Transactive memory or improved communication? ***Organizational Behavior and Human Decision Processes***, 82(1): 117-133.

O'Leary, M. B., & Cummings, J. 2007. The spatial, temporal, and configurational characteristics of geographic dispersion in work teams, ***MIS Quarterly,*** 31(3): 433.

O'Leary, M. B., & Mortensen, M. 2005. Subgroups with Attitude: Imbalance and Isolation in Geographically Dispersed Teams, ***Academy of Management***. Honolulu, Hawaii.

Pisano, G. P., Bohmer, R. M. J., & Edmondson, A. C. 2001. Organizational Differences in rates of learnings: Evidence from the adoption of minimally invasive cardiac surgery. ***Management Science***, 37(6): 752.

Raelin, J. A. 1997. A Model of Work-Based Learning. ***Organization Science***, 8(6): 563-578.

Schon, D. 1984. ***The Reflective Practitioner***: Basic Books.

Senge, P. M. 1990. ***The Fifth Discipline***. New York: Doubleday.

Sole, D. L., & Edmondson, A. C. 2002a. Bridging Knowledge Gaps: Learning in Geographically Dispersed, Cross-functional Development Teams. In N. Bontis, & C. W. Choo (Eds.), ***Strategic Management of Intellectual Capital and Organizational Knowledge***. Oxford: Oxford University Press.

Sole, D. L., & Edmondson, A. C. 2002b. Situated Knowledge and Learning in Dispersed Teams. ***British Journal of Management***, 13(Special Issue on Organizational Learning and Knowledge Management): S17-S24.

Stasser, G., Stewart, D., & Wittenbaum, G. 1995. Expert roles and information exchange during discussion: The importance of knowing who knows what. ***Journal of Experimental Social Psychology***, 31: 244-265.

Straus, S. G., & Olivera, F. 2000. Knowledge Acquisition in Virtual Teams. ***Research on Managing Groups and Teams***, 3: 257-282.

Townsend, A. M., DeMarie, S. M., & Hendrickson, A. R. 1998. Virtual teams: Technology and the workplace of the future. ***Academy of Management Executive***, 12(3): 17-29.

Watson-Manheim, M. B., Chudoba, K., M. , & Crowston, K. 2002. Discontinuities and continuities: A new way to understand virtual work. ***Information Technology & People***, 15(3): 191.

Wegner, D. M. 1987. Transactive memory: a contemporary analysis of the group mind. In G. Mullen, & G. Goethals (Eds.), ***Theories of group behavior***: 185-208. New York: Springer-Verlag.

Wong, S.-S. 2004. Distal and local group learning: Performance trade-offs and tensions. ***Organization Science***, 15(6): 645-656.

# TABLE 1

## Description of Development Projects and Teams

| Project Team | Development Task | Task Complexity [a] | Team Composition | # of Core Members | # of Sites Involved [b] | # of Countries | # of Languages | # of Contacts | # of Learning Episodes |
|---|---|---|---|---|---|---|---|---|---|
| GROSSO | Develop new product for high-margin market segment using new product and process technology | High | Research Scientist*<br>Experimental Scientist<br>Process Development Engineer<br>Materials Specialist<br>Production Engineer<br>Global Market Manager | 6 | 4 (+3)<br>SiteC<br>SiteD<br>SiteV<br>SiteW | 5 | 1 | 16 | 9 |
| BIANCO | Develop new product for strategic new customer using combination of existing product and process technologies | Medium-High | Product Development Engineer*<br>Process Team Leader<br>Technical Specialist<br>Research Scientist<br>Global Market Manager (US)<br>Regional Market Manager (JP)<br>Regional Commercial Manager (JP) | 7 | 5 (+2)<br>SiteB<br>SiteH<br>SiteI<br>SiteT<br>SiteW | 3 | 2 | 10 | 13 |
| CHIARO | Develop replacement products for existing profitable market through novel process technology | Medium-High | Production Development Engineer*<br>Market Development Manager<br>Experimental Scientist<br>Process Design Engineer<br>Production Supervisor<br>Market Manager (Europe) | 6 | 3 (+1)<br>SiteD<br>SiteS<br>SiteW | 2 | 1 | 12 | 10 |
| GRIGIO | Develop new product for existing customer, using combination of existing process technology | Medium | Product Development Engineer*<br>Research Scientist<br>Research Technician<br>Process Team Leader<br>Technical Service Representative<br>Sales Account Manager | 6 | 3 (+2)<br>SiteH<br>SiteW<br>SiteX | 2 | 1 | 9 | 7 |
| SCURO | Develop replacement products for existing market using combination of existing process technology | Medium | Production Engineer*<br>Production Engineer<br>Process Technician<br>Technical Service Representative<br>Sales Account Manager | 5 | 3 (+3)<br>SiteC<br>SiteH<br>SiteX | 2 | 2 | 6 | 4 |
| ROBUSTO | Develop improved process technology for platform production process | Medium | Research Engineer Specialist*<br>Process Specialist<br>Materials Specialist<br>Production Engineer<br>Production Technician<br>Maintenance Engineer | 6 | 3<br>SiteC<br>SiteH<br>SiteW | 2 | 1 | 6 | 4 |
| NERO | Develop replacement product for important customer, using existing process technology | Low | Applications Development Manager*<br>Experimental Scientist<br>Production Engineer<br>Sales Account Manager | 4 | 3 (+1)<br>SiteH<br>SiteW<br>SiteX | 2 | 1 | 7 | 4 |

a Internal project evaluation criteria; b Number in brackets indicate close interaction with customers and / or supplier; * Project team leader (PTL)

# TABLE 2

## Classification and Examples of Virtual Team Learning Practices

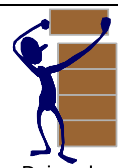
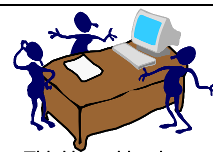
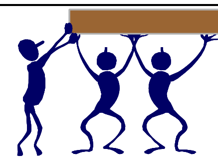
| | *THINKING ALONE* | *DOING ALONE* | *THINKING WITH OTHERS* | *DOING WITH OTHERS* |
|---|---|---|---|---|
| |  Thinking alone |  Doing alone |  Thinking with others |  Doing with others |
| | | *Markers* | | |
| Mode of Learning | Abstract conceptualization and reflection: e.g. analysis, reasoning, book research, idea generation | Active experimentation and concrete experience: e.g. experimentation, observation | Abstract conceptualization and reflection: e.g. idea generation, brainstorming, reasoning, discussion, conclusions. | Concrete experience and experimentation: e.g. experimentation, observation |
| Participation strategy | Individual responsibility or effort | Individual responsibility or effort | Collective responsibility and effort | Collective responsibility and effort |
| | | *Illustrative Data* | | |
| | [CHIARO's chosen technique] seemed to be the best option for the cost we could afford.. …If you really look at the science of it, if you look to the viscosity range, if you look to the technical parameters you're working with … there's no reason why it shouldn't work. My biggest concern in the early days was, were we on the edge of this technical range? My only concern was, were we between two stools – should we go with [another technique] or [the chosen technique]? (CHIARO, Market Development manager) | I'm largely the expert for testing samples – I would run things like that on my own. (GROSSO, experimental scientist)<br><br>I've run many trials here at SiteW, but the major one, the last one, was last November when we again produced suitable film for [the customer]. (NERO, experimental scientist)<br><br>Basically my role in [BIANCO trials] is to mix the coatings up, ensure the coating head is set up properly, and try to get the best coat quality to the film that I can. And while that's going on I keep data … I'll run some tests…. I work with the operating team in production as far as getting the coating on the film; with the assistant operator who's in the lab. He and I will look at the film together to compare the coat quality. But the test I do independently. (BIANCO, Experimental engineer) | And we tried a new chemical … It was [through talking to] both new [colleagues from the other company] and then present [colleagues in the existing company]…It's built on the knowledge that everyone had… (NERO, experimental scientist).<br><br>I was just talking to [X & Y] because I knew we used some [similar ingredients] somewhere on site. And [X] said, what're you doing? And I told him. And he said, "'well we're actually making some [of that] right now using some masterbatch - it's about what you'd need. I can have a barrel made and put off to the side." …. (BIANCO, Development Engineer)<br><br>We had a brief meeting … Essentially [we were] saying what we're going to do [on pilot facilities], what's different to the trials we've done before. … I learned from the [SiteH] trial that you need about 3 or 4 'goes-around' with the trial plan to make sure you cover everything. (GROSSO, Research scientist) | When we got the chance to meet in January we could talk in a lot more depth and show each other samples and ways of working. And I got to know and see how [the team leader] works over there and, although I'm not in my own environment, he obviously saw how I worked and interacted with other people while I was over there at the plant in SiteH." (NERO, experimental scientist)<br><br>Our first trial was strictly to get the [co-extrusion] block to work using information from SiteD and elsewhere. We started where they left off and tried to get [the technique] to work on this site. [The process team leader] ran the project. … He was teaching me since he's experienced this from a production end. I had worked with [electrical] controls on [co-extrusion] blocks so I helped there. We merged together – he taught me what I needed to know and I helped him on the control end. (GRIGIO, Process Engineer) |

**FIGURE 1**

**Development Work as Team-based Experiential Learning**

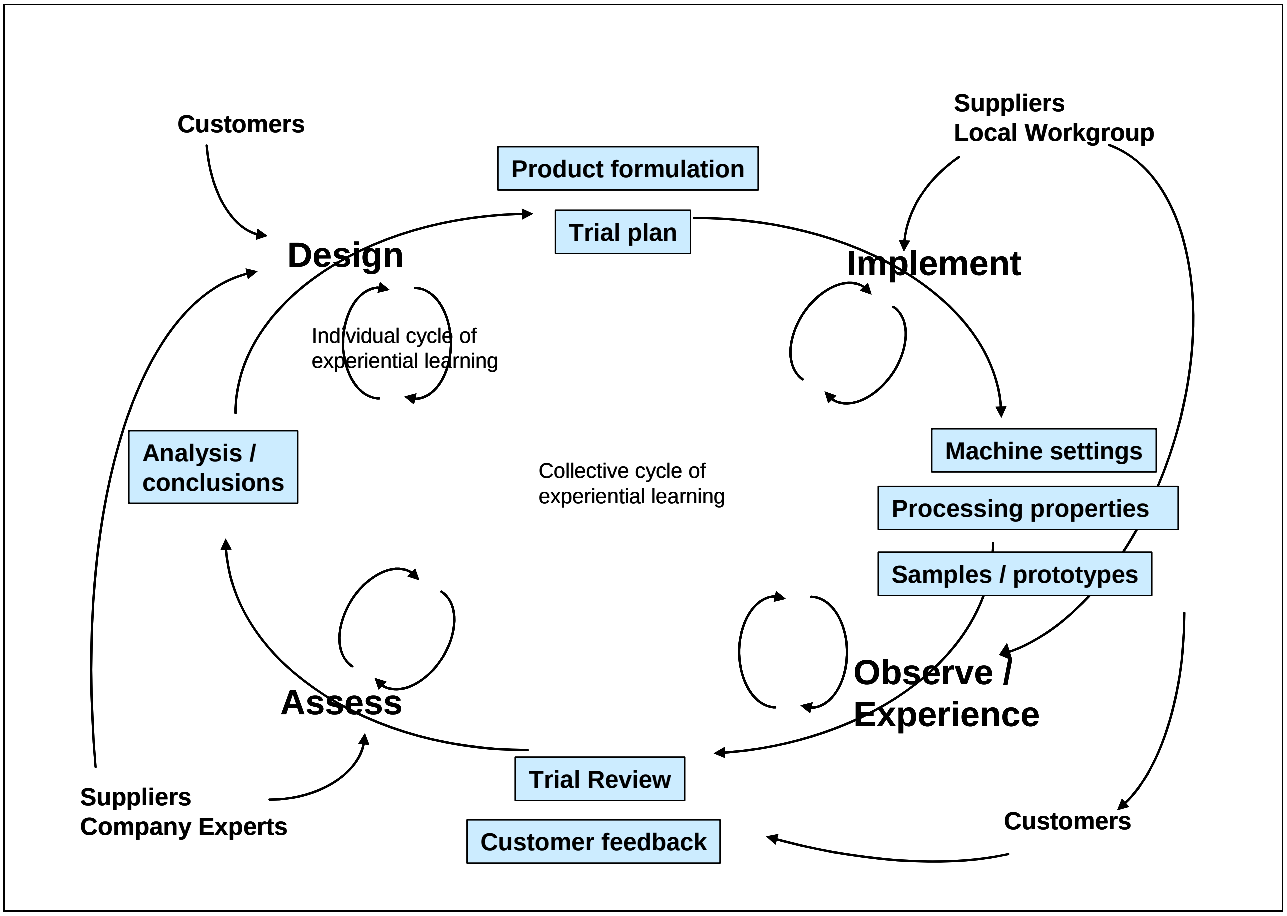


**FIGURE 2 A TYPOLOGY OF VIRTUAL TEAM LEARNING PRACTICES**